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ENVIRONMENTAL HARMONY-TYPE PAVEMENT BLOCKS MADE FROM CLAY AND WASTE GFRP

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ABSTRACT

To recycle glass fiber reinforced plastic (GFRP) discarded as industrial waste, we have proposed a process that produces porous glass fiber-reinforced ceramics by mixing clay and crushed GFRP before the mixture is fired. In this study, we aimed at developing environmentally friendly pavement blocks that could decrease the heat island phenomenon, prevent the inundation of roads caused by sudden heavy rain and decrease air pollution in urban areas by focusing on recent environmental issues. First, various ceramics were developed by changing the mixing ratio of clay and crushed GFRP, and their fundamental properties such as densities, porosities, pore size distributions, water absorptions and bending strength were examined. The results indicated that a porous pavement block with a high permeability and water absorption capacity could be produced by utilizing ceramics made from clay and waste GFRP. Next, the temperature changes caused when ceramic and mortar samples were irradiated with infrared light were measured. The results indicated that the ceramic had the ability to reduce radiant heat through evaporation. Finally, the NO_2 gas adsorption performance of the ceramics made from clay and GFRP was compared with those of various other materials, such as metals, plastics, wood, mortar and ceramic made from clay alone. The results also indicated that ceramics made from clay and GFRP had a high NO_2 gas adsorption ability. It is anticipated that ceramics made from clay and waste GFRP could be used as a material for pavement blocks that act as a countermeasure to the heat island phenomenon, sudden heavy rain and air pollution

***KEYWORDS:** Waste GFRP, Recycling, Pavement Block, Radiant Heat, NO_2 Adsorption*

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Original Article

INTRODUCTION

To recycle GFRP discarded as industrial waste, we have proposed a process that produces porous glass fiber-reinforced ceramics by mixing clay and crushed waste GFRP before the mixture is fired [1-3]. In developing new materials using waste, it is very important to attain a low manufacturing cost as well as to carefully clarify the overall usefulness and valuable usage situations. Recently, countermeasures against the heat island phenomenon, sudden heavy rain in urban areas and air pollution due to NO_x and PM 2.5 etc. have become issues of capital importance. Therefore, we have focused on these environmental issues and aimed at developing environmentally friendly pavement blocks that could decrease solar radiation heat and that had permeability as well as an air cleaning function.

First, to examine whether ceramics made from clay and GFRP can be used as a material for pavement blocks with their functions, various ceramics by changing the mixing ratio of clay and crushed GFRP are made. Following this, their fundamental properties such as densisties, porosities, pore size distributions, water absorptions and bending strengths are examined. Next, to examine the radiant heat reducing performance on the ceramic made from clay and GFRP, the surface temperature changes caused when the ceramic and mortar samples were irradiated with infrared light are measured. Then, the permeability of ceramics is also examined. Lastly, ceramic NO_2 gas adsorption performance is compared with those of various materials, such as metals, plastics, wood, mortar, and ceramics made from clay alone. From the results, it is confirmed that the ceramic made from clay and waste GFRP could be used for pavement blocks as countermeasures against the heat island phenomenon, guerrilla-type heavy rain and air pollution.

MANUFACTURING OF CERAMICS USING WASTE GFRP AND THEIR PROPERTIES

Ceramic Production

Figure 1 shows the raw materials used for producing the specimens. Figure 1(a) is clay produced in Miyazaki Prefecture, Japan, for use in the manufacturing of brick or tile. Figure 1(b) shows GFRP (polyamide plastic) containing 40% glass fiber. Figure 1(c) shows the glass fiber that is included in the GFRP. Table 1 shows the GFRP and clay in organic chemical compositions after firing, and the chemical compositions of the ceramics made by mixing clay and GFRP. Specimens were

Produced using the following procedures:

- Clay and GFRP were crushed using a rotary mill (Osaka chemical Co., Ltd., Japan, type: New Power Mill PM-2005), and then sifted using a 0.5 mm mesh screen.
- The crushed GFRP (0 to 60% of its total mass) was mixed with the clay.
- The mixtures were solidified by being pressed into molds at 10 MPa.
- The molded samples were heated in an oxidizing atmosphere at 100 $°C \cdot h^{-1}$ up to 1000 °C using an electric furnace. The samples were held at firing temperature for 1 h, and then cooled to room temperature in the furnace.

Density, Apparent Porosity and Pore Distribution

Figure 2 shows an example of a specimen made from clay and GFRP and its surface structure. We can find glass fibers in the clay structure of the specimen. Figure 3(a) shows the densities of specimens made from clay and GFRP. Specimens became lighter as the mixing ratio of GFRP increased because the plastic component was decomposed during firing. Densities ranged from 0.8×10^3 to 1.8×10^3 kg/m^3. Brick densities ranged from 1.6×10^3 to 3.7×10^3 kg/m^3 and the concrete density was approximately 2.4×10^3 kg/m^3 [4]. The specimens made from clay and crushed GFRP were very light in comparison. Figure 3(b) shows the apparent porosities of the ceramics. The porosities of the ceramics increased as the mixing ratio of GFRP increased. It was found that ceramics possessing high porosities of approximately 50% or more can be made using waste GFRP containing 40% glass fiber.

Figure 3(c) shows the water absorption of the ceramics. The absorption of water by the specimens increased as the mixing ratio of GFRP increased because of the increase in void space. These specimens also displayed comparatively-high water absorption, considering that the water absorption of a common brick is less than 15% (Japanese Industrial Standard R1250).

Table 1: Chemical Compositions of Inorganic Substances Contained in Clay, GFRP and Ceramics Made from Clay and GFRP

Component	Clay (Mass %)	Inorganic Matter Included in GFRP (Mass %)	Ceramics Made from Clay and GFRP (Mass %)		
			Mixing Ratio of GFRP		
			20%	40%	60%
SiO_2	65.8	45.5	64.6	62.8	60.7
Al_2O_3	21.9	11.9	21.2	20.5	19.7
Fe_2O_3	4.79	2.38	4.53	4.26	3.73
K_2O	3.37	0.19	2.98	2.63	2.11
MgO	1.67	0.83	1.46	1.33	1.31
CaO	1.31	37.1	4.07	7.33	11.3
TiO_2	0.87	1.00	0.87	0.83	0.80

Figure 1: (a) Clay, (b) Polyamide Plastic Composed of 40% Glass Fiber and (c) Glass Fiber included in GFRP

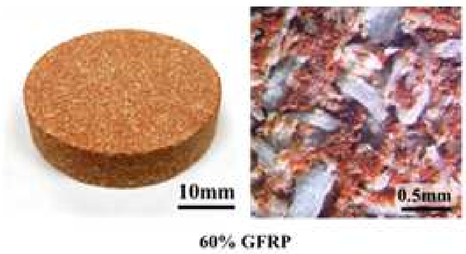


Figure 2: A Specimen made from Clay and GFRP and its Surface Structure

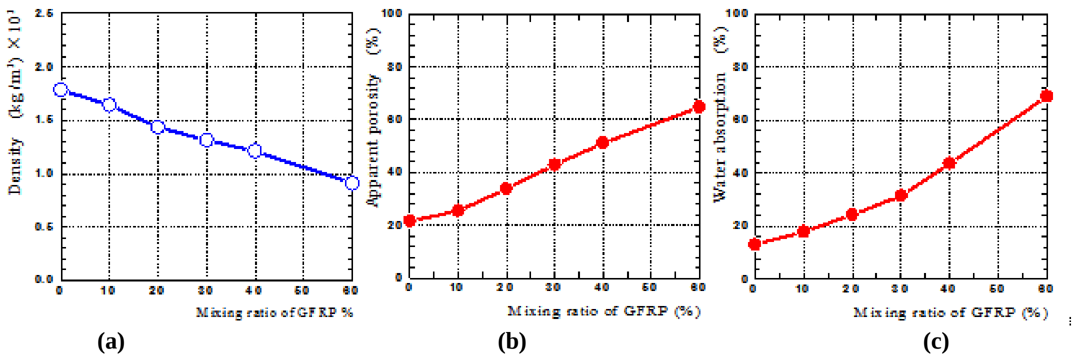


Figure 3: Densities, Apparent Porosities and Water Absorption of Specimens Made from Clay and GFRP

Figure 4 shows the pore size distributions of the ceramics. The ceramics made from clay alone had many pores of several micrometers or less. The specimens made from clay and GFRP had increasingly large pore sizes as the mixing ratio of GFRP increased. The pore diameters ranged from several micrometers to several tens of micrometers.

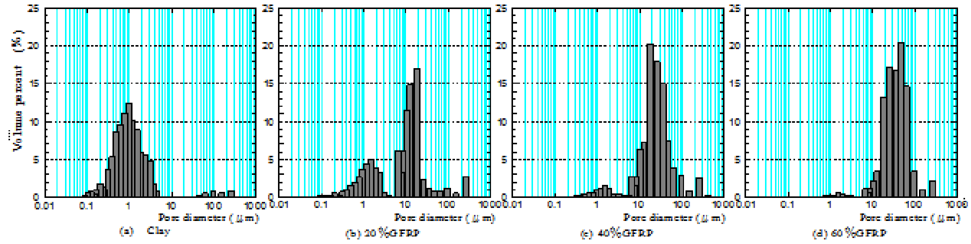


Figure 4: Pore Size Distributions

Ceramic Bending Strength

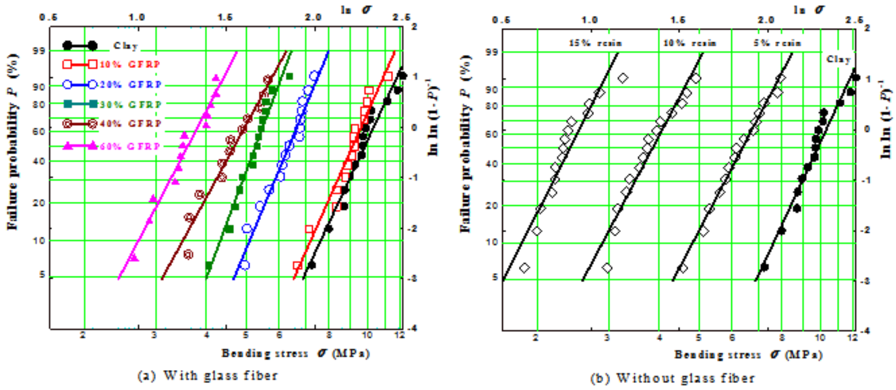


Figure 5: Bending Strength of Ceramics

Figure 5 shows Weibull plots for the bending strength of specimens made by mixing from 0 to 60% GFRP containing 40% glass fiber with clay, and that of porous specimens without glass fiber and made from clay and resin. Here, for specimens with glass fiber, we should notice that the mixing ratio of the resin was 6 % in the case where 10% GFRP with clay was mixed because the content of resin contained in GFRP was 60%. Ceramic bending strength decreased exponentially as the resin mixing ratio increased. Compared with the bending strength of porous specimens without glass fiber, the bending strengths of specimens made from clay and GFRP were apparently high. From the result, it was confirmed that porous ceramics made from clay and GFRP were reinforced by glass fiber. A bending strength of 3 MPa or more is required for sub-base materials such as the interlocking blocks used in pavement [5]. Ceramics made from clay and GFRP meet this criterion when the mixing ratio of GFRP is approximately 40% or less.

FUNCTIONALITIES OF CERAMICS MADE FROM CLAY AND WASTE GFRP

Ability of Ceramics to Reduce Radiant Heat

To examine how much a ceramic's surface temperature is increased by radiant heat, the temperature changes on the ceramic and mortar sample surfaces were measured when their surfaces were irradiated with infrared light. Figure 6 shows a schematic illustration of the temperature measurement setup. A commercial halogen heater (Takagi Co. Ltd., Japan, type: HL-501S, electric power for lighting: 500 W) was used to irradiate the sample with infrared light. A ceramic sample made by mixing 20% GFRP with clay and a mortar sample were used for the tests. For the ceramic production, the mixture of crushed GFRP and clay was solidified under a pressure of 5 MPa applied by a press machine (Shimadzu Corp., Japan, type: AG-X50kN), and was then sintered at a firing temperature of 1000 °C. The mortar sample was made by

mixing fine aggregate with ordinary Portland cement. The mixing ratio of the Portland cement to the fine aggregate was 1 to 1. The ceramic and mortar samples were 100 mm long squares that were 10 mm thick. Irradiation using infrared light was carried out in a darkroom. The light intensity near the sample surfaces was 1845 cd, and the illuminance was 19910 lx. The temperatures of the front and rear sample surfaces were measured using thermocouples. It has been found that the use of water retentive blocks for pavement can lower surface temperatures more than conventional pavement blocks due to the loss of heat through evaporation. Therefore, to examine the influence of water vaporization heat on the surface temperature of samples, dry samples and samples absorbing water were used for the experiments. Water absorption of the ceramic sample was approximately 26%. That of the mortar sample was approximately 6%. Here, the dry masses of the mortar sample and ceramic sample were 204g and 164g, respectively.

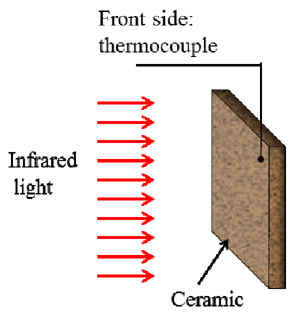


Figure 6: Measurement of Temperature Change Caused by Radiant Heat

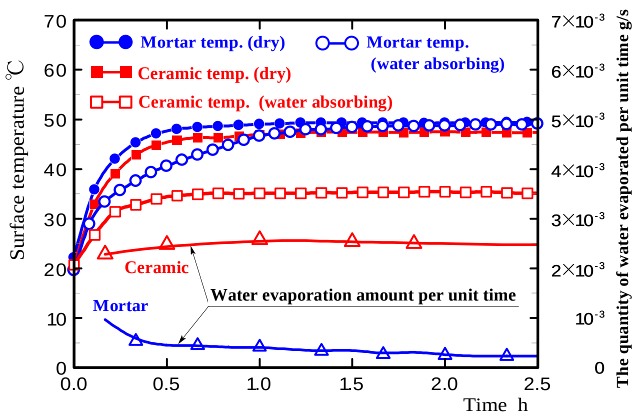


Figure 7: Surface Temperature of Ceramic and Mortar Samples

Figure 7 shows the change in temperature of the front surface, and the quantity of water evaporated per unit time from each sample when the front surface of the sample was irradiated with infrared light. The surface of the dry ceramic sample became almost the same temperature as the mortar sample. The surface temperature of the ceramic sample containing water was lower than that of the mortar sample containing water. It is believed that a larger amount of heat had been absorbed from the ceramic sample by evaporation because the quantity of water evaporated per unit time from the ceramic sample was more than that of mortar sample. From the above, it was clarified that the ceramic made from clay and waste GFRP had a radiant heat reducing ability by the evaporation of heat in water vapor, like water retentive blocks.

Permeability of Ceramics

A water permeable paving block has the advantage of precluding puddles. To examine the permeability of the

ceramics, permeability tests were carried out based on a falling head permeability test of soil (JIS A1218). Figure 8 shows a schematic illustration of the permeability test. Ceramic permeability was evaluated by calculating the coefficient of permeability using the following equation (1):

$$k_T = 2.303 \frac{aL}{A(t_2 - t_1)} \log_{10} \frac{h_1}{h_2} \tag{1}$$

k_T: Coefficient of permeability [cm/s], a: Cross sectional area of a cylinder [cm^2]

L: The thickness of the sample [cm], A: Cross sectional area of a sample [cm^2]

h_1, h_2: Water level at the time t_1, t_2 [cm]

Figure 9 shows the coefficient of permeability for ceramic specimens. A water permeable paving block has a coefficient of permeability of 0.01 and over (cm/s). The results indicated that the ceramics made from clay and GFRP water could be passed through water comparatively well compared to the ceramic made from clay alone.

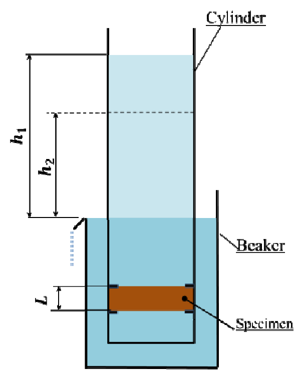


Figure 8: Schematic Illustration of a Permeability Test

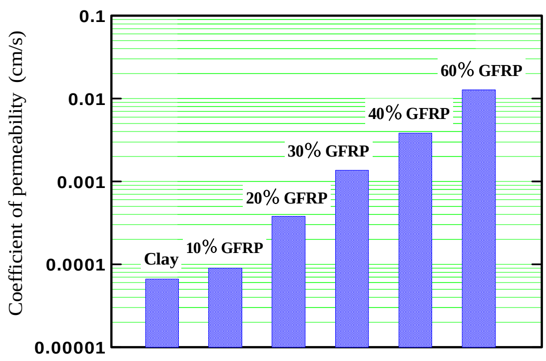


Figure 9: Permeability of Ceramics

NO_2 Gas Adsorption Ability of Ceramics

Figure 10 shows a schematic illustration of the experimental apparatus for NO_2 gas adsorption tests. Figure 11 shows an example of samples used for the experiments. Carbon steel, aluminum alloy, PVC plastic and Japanese cedar, which are commercially available materials, mortar samples, ceramic samples made clay alone and by mixing 40% GFRP with clay were used for the experiments. With a sample in the sealed container, we allowed the air-NO_2 gas mixture with

approximately 10 ppm NO_2 to pass through the sealed container at a constant flow rate for 10 minutes without being recirculated. The flow rate was 0.5 L/min. The NO_2 concentration in sampling bag B was then measured through a sampling port.

Figures 12 (a) and (b) show the reduction amount of NO_2 concentration per unit volume and per mass of each sample, respectively. Figures 13 and 14 show the porosity and specific surface area of each sample, respectively. Here, the measurements of the specific surface area were carried out on porous materials only. The results indicated that metals and plastics do not adsorb NO_2 gas well, whereas Japanese cedar, mortar and ceramics adsorb NO_2 gas very well. From the results shown in Figures 13 and 14, it is believed that materials with many fine pores as well as large specific surface area adsorbed NO_2 gas well. The NO_2 reduction amount per unit volume was the largest for ceramics made from clay alone. The NO_2 reduction amount per unit mass by Japanese cedar was the largest because of its light weight.

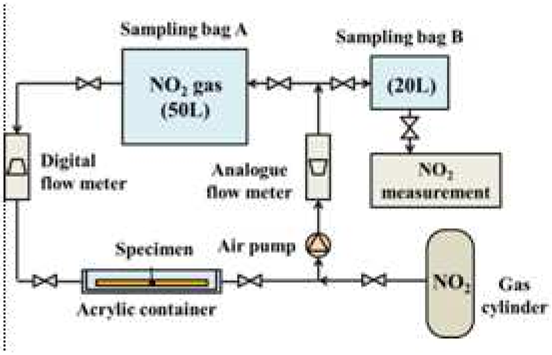


Figure 10: Experimental Apparatus for NO_2 Gas Adsorption and Removal Tests

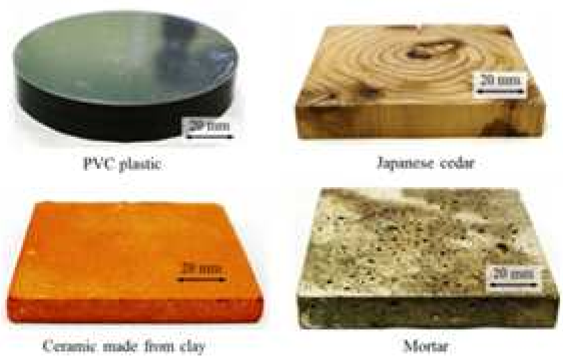
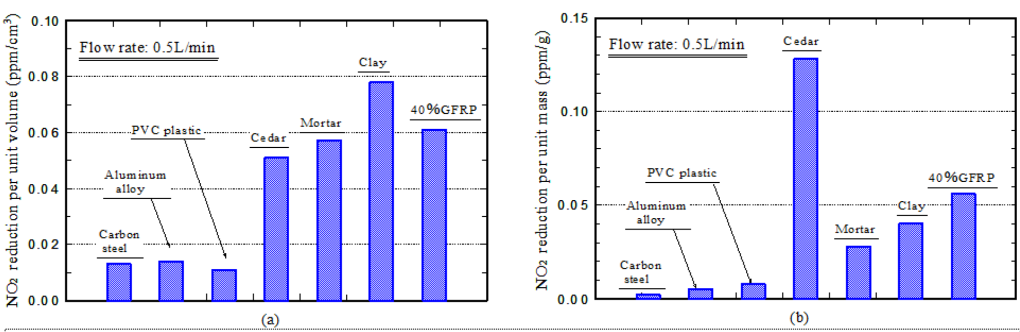


Figure 11: Various Materials Used for NO_2 Gas Adsorption and Removal Tests



(a) NO_2 reduction per unit volume (b) NO_2 reduction per mass

Figure 12: Comparison of NO_2 Reduction Amount for Various Materials

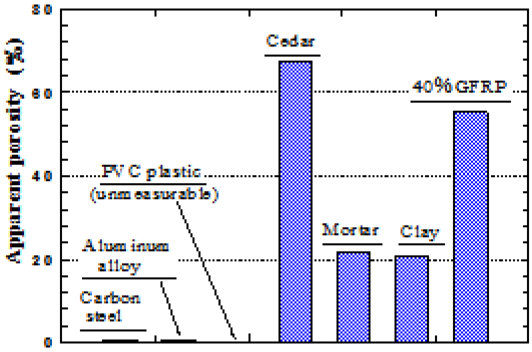


Figure 13: Apparent Porosities of Various Materials

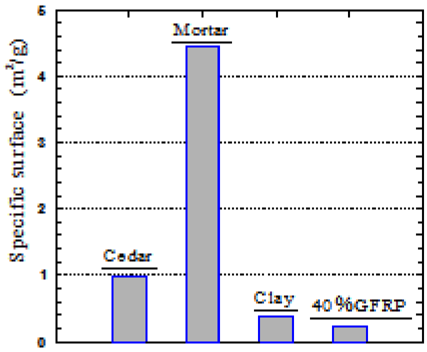


Figure 14: Specific Surface Areas of Various Materials

Thus, when considering the overall performance, ceramic made from clay and GFRP exhibited a high reduction ability both per unit volume and mass compared with other materials examined.

CONCLUSIONS

In this study, in order to effectively utilize of porous ceramics made from clay and waste GFRP, we developed a multi-functional environmentally friendly pavement block. The obtained results were as follows:

- It was confirmed that porous ceramics which sufficiently satisfied the strength standards required for a pavement block could be made using waste GFRP.
- From measurements of the surface temperature changes caused when a ceramic sample made by mixing 20% GFRP with clay and mortar sample were irradiated with infrared light, it was clarified that the ceramic could highly decrease the radiant heat by evaporation because it had a high water absorption capacity.
- It was confirmed that a pavement block with a good permeability could be made from clay and waste GFRP.
- Ceramic made from clay and GFRP had a high adsorption ability both per unit volume and mass for NO_2 gas.
- From above results, it is expected that the ceramic made from waste GFRP and clay could be used as a material for pavement blocks as countermeasures against the heat island phenomenon, sudden heavy rain and air pollution.

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